Novel Compression and Fueling Apparatus to Meet Hydrogen Vehicle Range Requirements

Todd Carlson
Future Energy Solutions
Air Products and Chemicals, Inc.
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Contributors:
Bharat Bhatt (Process Design)
Bob Byerley (Process Controls)
David Chalk (Machinery Design)
Simone Kothare (Dynamic Modeling)
William Kottke (Process Design/Machinery)
Jorge Mandler (Advanced Controls)
Nick Pugliese (Fabrication)

FY 04 Objectives

- Primary
  - Develop a process design for a novel compressor
  - Identify potential hydraulic fluids
  - Complete technical/economic evaluation of system
- Secondary
  - Investigate other fueling components to support 700 barg (10,000 psig) hydrogen fueling

Budget

	To Date	Remaining	Total
Labor	$290,141	$ 155,833	$ 445,974
Materials	$19,481	$ 225,420	$ 244,901
Total	$309,622	$ 381,253	$ 690,875

- **50% Cost Share**
- **Special Program through Pennsylvania Department of Environmental Protection**

Technical Barriers and Targets

- Technical Barriers
  - High Cost of Hydrogen Compression
  - High Cost of Storage and Dispensing
  - Cost of Hydrogen

- FY 05 Targets
  - $0.29/kg cost of compression
  - $0.19/kg cost of storage and dispensing
  - 85% efficient compression
  - $3/kg hydrogen fuel

Approach

- Conceptual Design
- Process Design
- Thermodynamic Data
- Fluid Selection and Testing
  - Measure hydrogen solubility in various fluids
  - Test permeation of pressure transducer diaphragms at various pressures
- Dynamic Modeling
  - Evaluate compressor using a custom model
  - Optimize design, operation and control
  - Evaluate heat transfer issues and check isothermal assumptions
  - Evaluate sensitivity of unit to various design parameter upsets and operating conditions
- Component Design, Fabrication, and Testing
- Prototype
- Long Term Testing

Approach

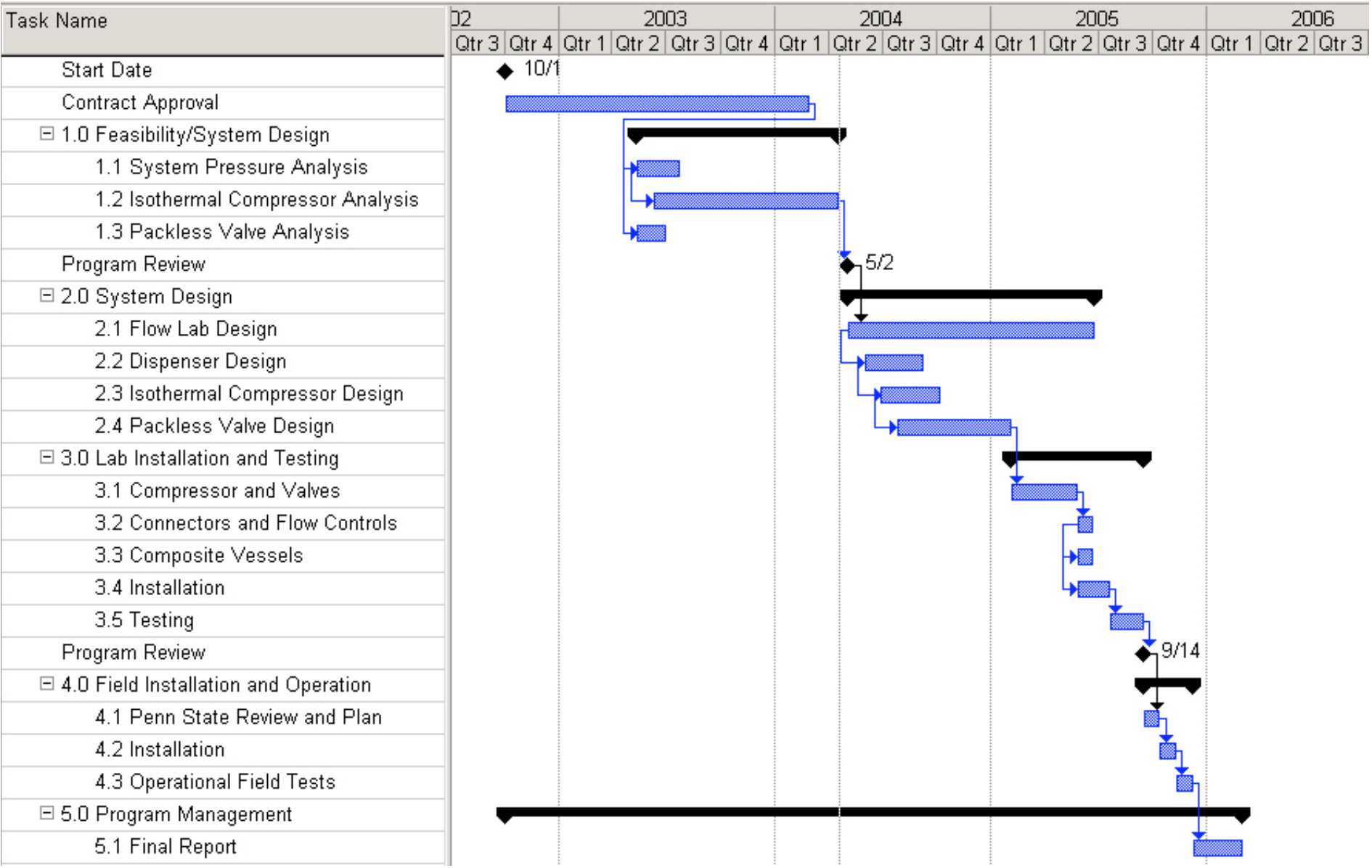
Design Issues

- Compressor
  - Isothermal
  - High pressure
  - Single stage
  - Low cost
- Fueling Station
  - Lower the delivered cost of hydrogen
  - Composite vessels
  - Breakaway and fuel nozzle
  - Fueling codes

Safety

- Air Products Hydrogen Experience
  - Over 10,000 fills (60/week)
  - 13 fuelers installed last year (>20 total, 6 in construction)
  - Industrial hydrogen (30+ years, 55% merchant market share, 1000 gaseous/500 liquid customers, pipelines, reformers, electrolysis)
- Internal Hazard and Operability Review
  - Divide system into nodes
  - Review deviations and effects
- Our fueling systems have undergone rigorous third party independent safety reviews
  - ABS Consulting – Singapore
  - NASA - White Sands, NM
  - KHK/JHPGSL – Kagoshima, Japan
- Management of Change, Near Miss Reporting, Quantified Risk Assessment, and other project management systems.

Timeline


Task Name
02
2003
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Qtr 4
Qtr 1
Qtr 2
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Qtr 3
Start Date
Contract Approval
1.0 Feasibility/System Design
1.1 System Pressure Analysis
1.2 Isothermal Compressor Analysis
1.3 Packless Valve Analysis
Program Review
2.0 System Design
2.1 Flow Lab Design
2.2 Dispenser Design
2.3 Isothermal Compressor Design
2.4 Packless Valve Design
3.0 Lab Installation and Testing
3.1 Compressor and Valves
3.2 Connectors and Flow Controls
3.3 Composite Vessels
3.4 Installation
3.5 Testing
Program Review
4.0 Field Installation and Operation
4.1 Penn State Review and Plan
4.2 Installation
4.3 Operational Field Tests
5.0 Program Management
5.1 Final Report
10/1
5/2
9/14

Technical Accomplishments
Novel Compressor – Basic Concept

- **No Mechanical Piston:** Gas compressed by liquid piston
- **Isothermal:** Gas cooled during compression
- **Single Stage:** Liquid piston permits high pressure ratio by elimination of piston to cylinder clearance concerns
- **Liquid Pump:** Inherently lubricates all dynamic seals
- **Dynamic Gas Seals Eliminated:** No gas seals to atmosphere
- **Issues:**
  - 14,000 psig hydraulic pump
  - Fluid selection
  - Level control
  - Inefficient pump
  - Fluid carryover

Patents Pending

many typical machinery issues eliminated by liquid piston

Technical Accomplishments
Hydraulic Fluid Selection

Criteria:

- Low viscosity for good flowing characteristics
- Low volatility to avoid contamination of downstream equipment and fluid loss
- Low H_2 solubility to minimize H_2 recycle
- Lubricating properties at high pressure to minimize pump wear

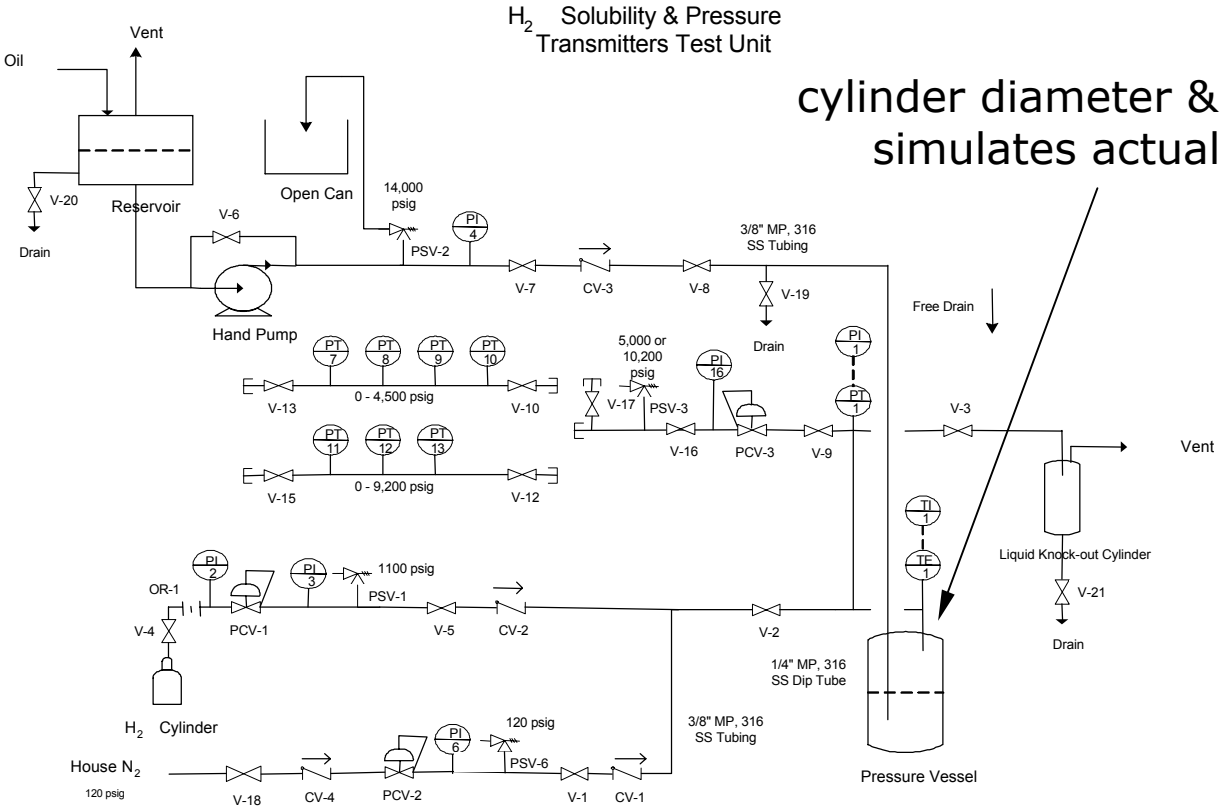
Problem:

- Hydrogen solubility data not available for fluid at high pressure

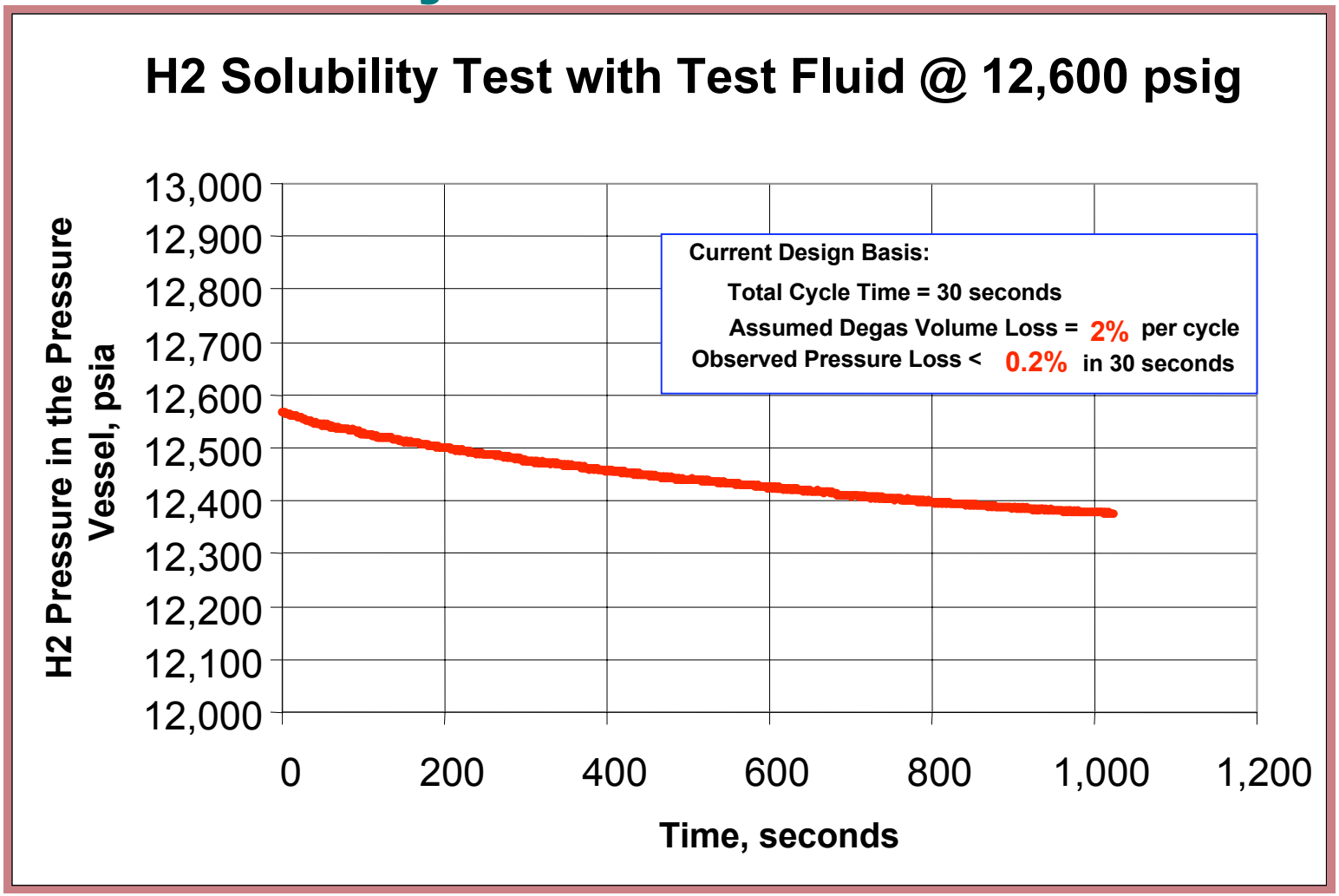
Technical Accomplishments

Fluid Solubility Test

- H_2 fills test chamber under pressure
- Fluid introduced, pumped in
- Pressure measured vs. time



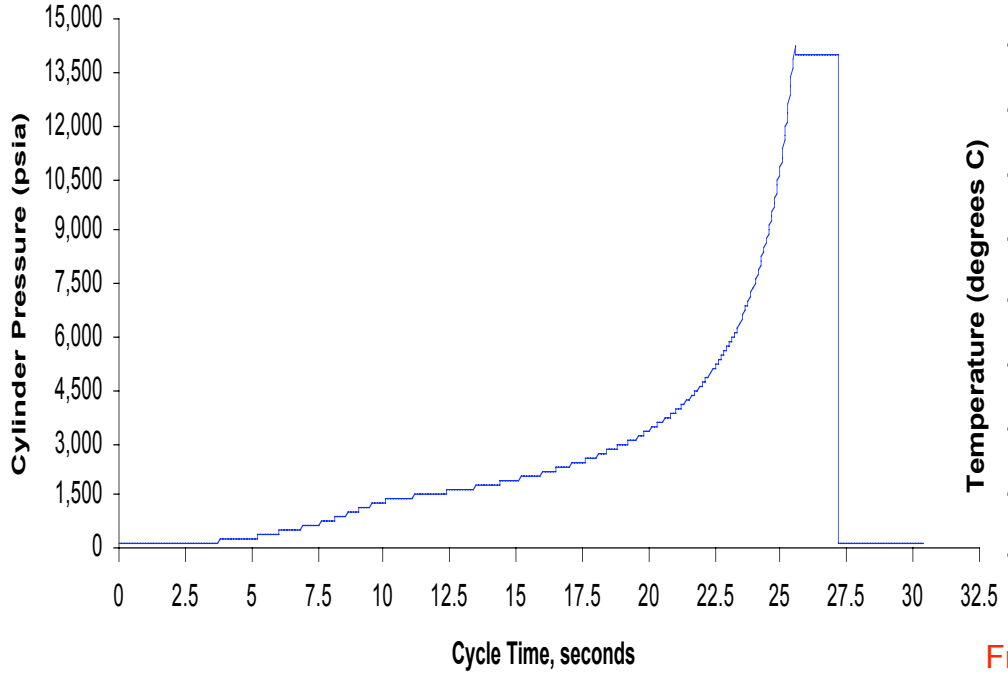
Technical Accomplishments
Pressure Decay



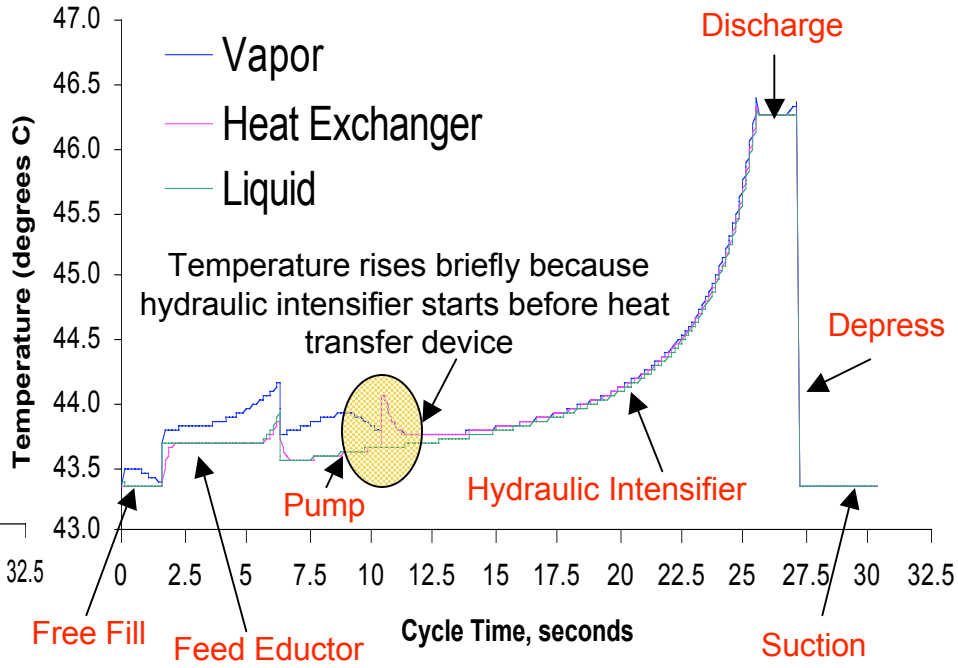
solubility well below acceptable limits

Technical Accomplishments
Cylinder Pressure and Temperature

Cylinder Pressure (psia) vs Time (sec)



Cylinder Temperature (ºC) vs Time (sec)



~ 3-4 ºC temperature rise for 140:1 compression ratio

Technical Accomplishments
Dyanamic Simulation Results

- Identified key operational issues and design parameters:
  - Surface area requirements in heat exchanger and heat transfer coefficients for near isothermal operation
  - Liquid inventory management needs (pressure/flow regulation)
- Quantitative results on potential sources of inefficiency:
  - Hydraulic intensifier friction
  - Circuit DPs
  - Hydrogen solubility in compression fluid
  - Heat transfer limits and design of heat exchanger
- Process sensitivities to the following parameters studied:
  - Initial accumulator gas volume
  - Pump flow
  - Hydraulic intensifier flow
  - Valve flow coefficients

novel H_2 compressor unit is feasible

Technical Accomplishments
Pressure Analysis

- All automotive OEM's are pursuing 700 barg fueling to achieve US norm of 300 mile range.
- Fast fill (~ 3 minutes) is the only method that has commercial potential.
- Cascade fueling is the most promising method of achieving a low cost, fast fill.
- Cascade filling requires a minimum of 25% overpressure to counter vehicle tank heating.
- Fast fill to 700 barg will require cooling of the hydrogen on most days.
- ASME and Air Products requirements for relief valves (set at vessel MAWP) impose a maximum operating pressure of 90% of MAWP.

(700 Barg * 125%) / 90% = 972 Barg MAWP (14100 psig)

System pressure requirement is 14100 psig MAWP

Technical Accomplishments
Fueling Apparatus

- **Air Products has developed hydrogen fueling systems up to 700 barg (10,000 psig).**
  - **Valves**
    - **Manual**
    - **Actuated**
    - **Pressure Control**
  - **Flexible Hose**
  - **Tubing**
  - **Fittings and Adapters**
  - **Controller**
  - **Packaging**

Most components available today for 700 barg fueling

FY 05 Next Steps

- Safety Review of Process / Hazard Review.
- Complete detailed design / drawings.
- Obtain quotes for all parts & purchase.
- Assemble and Test.
- Determine overall costs.
- Determine feasibility of future use.
- Long term prototype testing, if warranted.
- Scale-up unit, if warranted.

Interactions/Collaborations

- Air Products and Chemicals, Inc.
  - Future Energy Solutions
  - Advanced Systems Machinery
  - Advanced Controls
  - Dynamic Modeling
  - Corporate Safety

Questions?

Thank you

tell me more

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